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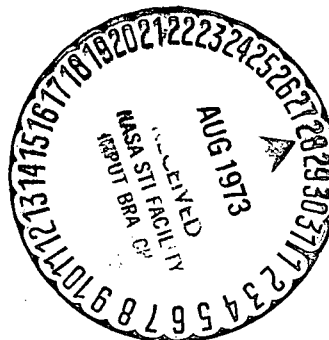
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REMOTE SENSING APPLICATIONS FOR
TRANSPORTATION AND TRAFFIC ENGINEERING STUDIES:
A Review of the Literature

By James W. Epps
Mississippi State University
Department of Civil Engineering
State College, Mississippi



Prepared for

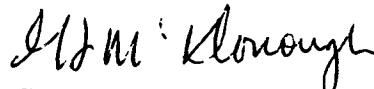
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16. ABSTRACT This report surveys current references for the application of remote sensing to traffic and transportation studies. The report presents topically the major problems that concern traffic engineers and transportation managers, summarizing the literature references that discuss remote sensing applications for each particular topic.					
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FOREWORD

Some of the most pressing environmental problems of urban areas today are directly attributable to or related to traffic and transportation conditions. When the MSFC Environmental Applications activity was initiated in 1971, one of the first requests for support to which the Center responded came from the City of New Orleans. The City and Metropolitan Area governments asked MSFC to cooperate with them in investigating the possible application of remote sensing and other space technology to this traffic transportation problem. After an initial feasibility study indicated favorable possibilities, the Regional Council of Governments of the Greater New Orleans Metropolitan Area adopted a project entitled Systematic Transportation Analysis Research (STAR) to expand the application project.

As a part of the NASA support provided, a number of area universities were funded through small contracts and grants to study various aspects of the problem. As part of the requirements of one such contract, NAS8-29036, Mississippi State University, was asked to survey current literature pertinent to the use of remote sensing for traffic and transportation study. The resulting survey is herein presented as a potentially valuable reference for other NASA elements and other agencies which may be conducting similar projects.



George F. McDonough
Director

Environmental Applications Office

Remote Sensing Applications
for
Transportation and Traffic Engineering Studies
A Review of the Literature

INTRODUCTION

The purpose of this report is to present a survey of the current literature concerning the applications of photographic techniques to transportation and traffic engineering studies. A survey of the literature is designed to illustrate the possible applications of remote sensing techniques to the solution of the same problems that have been analyzed in the past using ground time-lapse photography, aerial time-lapse photography, and sequential aerial photography. As the technology becomes available, remote sensing techniques will become economically feasible in such studies due to the coverage that can be provided using such techniques and the development of laser-oriented computer data reduction systems.

The report is subdivided into ten major sections. The first nine sections offer a brief description of the literature concerned with particular topics that offer the possibility of solution by remote sensing techniques. The topics are as follows: (1) General remote sensing technology, (2) Urban transportation studies, (3) Vehicle placement and vehicle

characteristics studies, (4) Traffic operations studies, (5) Interchange design studies, (6) Freeway ramp design studies, (7) At-grade intersection design studies, (8) Highway planning studies, and (9) Parking and pedestrian studies. The tenth section contains an annotated bibliography of the references included within the investigation.

Each section will offer a brief description of the literature relating to the particular topic and possible applications of remote sensing technology to the subject. At the end of each section a listing of the references related to the topic will be provided. A complete description and synopsis of each reference is provided in the annotated bibliography.

GENERAL REMOTE SENSING TECHNOLOGY

The authors of the five references concerning general remote sensing technology primarily addressed themselves to the potential of remote sensing in the solution of a wide range of urban problems. The Committee on Science and Astronautics (1972) presented an overall state-of-the-art concerning remote sensing and discussed aspects of the technology to which research and development should be directed initially. Wobber (1970) and Richter (1971) discussed the general advantages of remote sensing compared to other forms of data collection and offered several possible applications of the techniques. Kiefer and Scherz (1969) discussed the most recent advances in the technology of remote sensing and

general civil engineering applications of the technology. Future research needs in the field were also briefly discussed. Horton and Marble (1969) described the development of a regional information data base utilizing remote sensing data gathering techniques. Criteria for such an information system and the electronic equipment necessary for data reduction were described.

References

Committee on Science and Astronautics, "Remote Sensing of Earth Resources"

Wobber, "Orbital Photos Applied to the Environment"

Richter, "Urban Photo Index for Eastern U. S."

Kiefer and Scherz, "Civil Engineering Applications of Airborne Remote Sensing Technology"

Horton and Marble, "Regional Information Systems: Remote Sensing Inputs"

URBAN TRANSPORTATION STUDIES

The future potential of the applications of remote sensing technology in the field of urban transportation planning offers urban planners and engineers unlimited sources of data for their studies. The potential was found to be well referenced in the literature.

Osborn (1970), DeSalvo (1971), and Sweet (1969) discussed the future demands transportation will place on the urban areas of the country and the organization of the various agencies that will be required to meet these demands. Computer and remote sensing technologies were discussed as to the roles

each would play in the solution of future transportation problems. Dueker and Horton (1971), Bates (1970), Creighton, Hamburg (1971), and Moore and Wellar (1969) discussed the future data requirements of urban transportation planning. The development of information data banks for urban, state-wide, and regional planning was discussed as to current developments in technology that can now be utilized, technological developments that must be made, and organizational changes that must be made. Leser (1970) described a procedure where origin-destination studies were accomplished using ground photography. The advantage of using photographic techniques is that driver annoyance at being stopped is avoided. Remote sensing of targeted vehicles could offer the same results. Hutchinson (1971) presented no applications of remote sensing but described a procedure by which traffic patterns and flows could be predicted. Using data pertaining to the patterns of peak-hour trips (primarily work trips), the author developed a procedure which would generate total trip demand and flows.

Remote sensing techniques could be utilized to obtain data on the peak-hour flows from which total traffic demand could then be generated. Mittelbach and Schneider (1971) presented the most valuable research in the area of urban transportation planning. The various types of remote sensors that could be used for vehicle detection and applications of each sensor were discussed. Also discussed were the latest advances in technology which provide for immediate data reduction.

References

- Osborn, "Charting New Transportation Environment"
- DeSalvo, "Conference on Regional Transportation Planning, Proceedings: The Rand Corporation"
- Sweet, "Guidelines for the Administration of Urban Transportation Planning"
- Dueker and Horton, "Information Systems for the Urban Transportation Planning Process"
- Bates, "Development and Use of a Statewide Origin and Destination Data Bank"
- Creighton, Hamburg, "Data Requirements for Metropolitan Transportation Planning"
- Moore and Wellar, "Urban Data Collection by Airborne Sensor"
- Leser, "Photographic O-D Traffic Survey"
- Hutchinson, "Establishing Urban Transportation Demands by Synthetic Procedures"
- Mittelbach and Schneider, "Remote Sensing: With Special Reference to Urban and Regional Transportation Management"

VEHICLE PLACEMENT AND VEHICLE CHARACTERISTICS STUDIES

The analysis of these types of studies pioneered the uses of photographic techniques of data collection for traffic engineering studies. Johnson (1928) used aerial photography to analyze traffic flow characteristics along a 29-mile length of highway between Baltimore and Washington, D. C. Greenshields (1933) introduced time-lapse photography as a tool for analyzing traffic behavior. The efforts of these two men provided a basis for complete traffic monitoring system, and their methods have been used and improved upon for traffic research over the past 40 years.

Athol (1965), Herd (1968), and Authie, Giraud, and Leglise (1972) used aerial photographic techniques to determine the various operational characteristics of vehicles in a stream of traffic. Such parameters as vehicle speeds, headways, densities, relative speeds, and travel times were evaluated. The application of remote sensing techniques for analyzing these vehicle characteristics is obvious and would offer the distinct advantage of covering a much larger area and also minimizing vehicle placement error through computer reduction processes. Treiterer and Taylor (1966), Treiterer (1969), and Tolle (1971) used aerial photographs to provide traffic flow data to validate certain traffic flow models. In all three cases the aerial data proved to be quite reliable and remote sensing techniques would provide the same information with the advantages of reduced error and greater coverage. Haley, Hall, and Johnson (1963) related vehicle travel time to level of service in the development of a street improvement priority system. Although the study utilized no aerial photographic techniques, remote sensing techniques would provide the same data and, through computer reduction, provide the data much more accurately and quickly. Baggot (1966) presented the first attempts of using computer scanning of aerial photographs to obtain traffic measurements. Good results were obtained from photographs taken at 7,200 feet. The limitations of the system and technological advances needed to overcome these limitations were also discussed. A unique use of remote sensing was presented by Treiterer (1972) which utilized

remote sensing longitudinally between vehicles to reduce vehicle conflicts and rear-end collisions. Recommendations for implementation of the system and estimates of the system cost were also presented.

References

Johnson, "Maryland Aerial Survey of Highway Traffic Between Baltimore and Washington"

Greenshields, "The Photographic Method of Studying Traffic Behavior"

Athol, "Interdependence of Certain Operational Characteristics Within a Moving Traffic Stream"

Herd, "An Aerial Photographic Technique for Presenting Displacement Data"

Authie, Giraud, and Leglise, "Economy With Accuracy in Assembling Traffic Displacement Data by Aerial Photography"

Treiterer and Taylor, "Traffic Flow Investigations by Photogrammetric Techniques"

Treiterer, "Investigation of Traffic Dynamics by Aerial Photogrammetry Techniques"

Tolle, "The Lognormal Headway Distribution Model"

Haley, Hall, and Johnson, "Travel Time--A Measure of Service and a Criterion for Improvement Priorities"

Baggot, "Traffic Data Acquisition From Aerial Photographs by Photographic Image Processing"

Treiterer, "Longitudinal Traffic Control by Infrared Sensing"

TRAFFIC OPERATIONS STUDIES

Studies of traffic operations using photographic techniques have been conducted for almost 40 years. The methods used to date have been (1) time-lapse photography, (2) aerial

photography, and (3) continuous strip stereoscopic photography. The disadvantages of using these types of photography are numerous, but several of the most critical disadvantages are: (1) the film capacities of the cameras are very limited (only 30 minutes of filming can be conducted at one time), (2) coverage is limited, and (3) a reference system must be established on the ground in order to obtain reasonable traffic data.

Bleyl (1972) introduced a method which could be used to eliminate the problem of a reference system through the use of a fairly simple computer program. As yet, the other two problems have not been solved, but are being endured until technology can be implemented to solve them. Remote sensing will effectively solve both due to the fewer pictures needed and greater coverage provided. Bleyl's (1972) method could be implemented to solve any problems related to a reference system. McCasland (1963) compared time-lapse photography and continuous-strip stereoscopic photography with respect to traffic studies. The applications best suited to each type of aerial photography were outlined and discussed. Keese, Pinnell, and McCasland (1959) and Malo, Mika, and Walbridge (1959) presented applications of time-lapse photography to solve urban freeway congestion problems. Both studies developed techniques which were used to broaden the applications of aerial photography to other traffic studies, such as parking studies, accident studies, and freeway design studies. Everall (1972) discussed the latest advances in remote sensing and data reduction systems that could be applied to freeway

surveillance control systems. Everall (1972) felt, however that remote sensing has not been developed to the place where it is economically feasible for freeway surveillance yet. Bourne (1973), Pelog, Stoch, and Etrog (1969), Caggiano and Forte (in progress), Jordan (1963), Schaefer and West (1969), and Missouri (in progress) reported of freeway surveillance systems in operation across the country. The organization and equipment requirements as well as the data collection and analysis procedures were described in each case. Wagner and May (1963), Rice (1963), and May, Ahlborn, and Gillfillan (in progress) reported of freeway operations studies conducted by aerial photographic techniques. Density contour maps, travel time maps, and traffic flow maps were developed from the photographs and used to pinpoint congested areas of the freeways under study. Recommendations for improvements were made and implemented as a result of the analysis. Remote sensing techniques could be implemented for these purposes very easily providing the same advantages of coverage and minimization of error mentioned previously. Goodwin, Browne, and Lawrence (1972) and Munjal, Hsu, and Lawrence (1971) reported of aerial photography being utilized in the analysis of freeway lane-drop locations. In both cases, aerial photography provided extremely accurate data for the studies. Wildermuth (1971) and Humphreys (1970) studied the effect trucks had on freeway operations and Hodgkins (1964) studied the effect of buses on freeway operations. All three studies utilized time-lapse photography during the data collection

stages of the research. Remote sensing techniques would be quite adaptable for these studies because of the larger vehicle to be detected.

References

- Bleyl, "Traffic Analysis of Time-Lapse Photographs Without Employing a Perspective Grid"
- McCasland, "Comparison of Two Techniques of Aerial Photography for Application in Freeway Traffic Operations Studies"
- Malo, Mika, and Walbridge, "Traffic Behavior on an Urban Expressway"
- Keese, Pinnell, and McCasland, "A Study of Freeway Traffic Operations"
- Everall, "Urban Freeway Surveillance and Control: The State of the Art"
- Bourne, "Illinois Tollway is Easy Street With Total Communications System"
- Pelog, Stoch, and Etrog, "Aerial Photographs for Traffic Studies in Urban Areas"
- Caggiano and Forte, "Development of an Aerial Reconnaissance System for Transportation Operations Analysis"
- Jordan, "Development of Sky Count Technique for Highway Traffic Analysis"
- Schaefer and West, "A New Look in Freeway Operation"
- Missouri, "Freeway Surveillance Studies"
- May, Ahlborn, and Gillfillan, "Freeway Operations Study (District 04)"
- Wagner and May, "Use of Aerial Photography in Freeway Traffic Operations Studies"
- Rice, "Adoption of Aerial Survey Methods for Traffic Operations"
- Goodwin and Lawrence, "Investigation of Lane Drops"

Mujal, Hsu, and Lawrence, "Analysis and Validation of Lane Drop Effects on Multi-Lane Freeways"

Wildermuth, "Effects of Lane Placement of Truck Traffic on Freeway Flow Characteristics"

Humphreys, "Effects of Trucks on the Urban Freeway"

Hodgkins, "Effect of Buses on Freeway Capacity"

INTERCHANGE DESIGN STUDIES

The analysis of traffic operations within interchange areas is particularly suited to the use of aerial photographic techniques. In urban areas, traffic volumes can be heavy within the interchange area and analysis by ground techniques can be very dangerous.

Capelle and Pinnell (1961) used time-lapse photography to measure vehicle headways and delays in an attempt to determine proper design considerations for signalized diamond interchanges. Wattleworth, Archambault, and Wallace (1968) used aerial photography to evaluate the traffic operations on major freeway-to-freeway interchanges in Detroit. Remote sensing techniques could be utilized on either type of study because of the vehicle characteristics that would be measured in each case.

References

Capelle and Pinnell, "Capacity Study of Signalized Diamond Interchanges"

Wattleworth, Archambault, and Wallace, "Development of Techniques for Analysis of Operation of Major Interchanges"

FREEWAY RAMP DESIGN STUDIES

Freeway ramp design includes the design of four critical sections: (1) acceleration and deceleration lanes, (2) on-ramps, (3) off-ramps, and (4) weaving areas. Aerial photographic analysis of all four types of sections are well documented in the literature. In all cases, remote sensing techniques could be used to evaluate the vehicle characteristics necessary for the proper analysis or design of each section type. Primarily because of the safety aspects of using aerial photography, the coverage provided, and the minimal error associated with the use of such techniques, remote sensing provides a suitable method of analyzing freeway ramp situations.

Jouzy and Michael (1963) used time-lapse photography to evaluate the design of acceleration and deceleration lanes along Indiana freeways. The primary traffic characteristics evaluated were vehicle speeds and lane-changes. Taylor and Carter (1970), Hurst, Perchonok, and Seguin (1968), Wattleworth, Buhr, Drew, and Gerig (1967), McDermott and McLean (1963), Fukutome and Moskowitz, (1959), and Davidson (1957) analyzed on-ramps using either time-lapse or aerial photographic techniques. The primary vehicle characteristics evaluated were: (1) vehicle entrance speed, (2) acceleration lane usage, (3) relative speeds between merging vehicle and freeway vehicle, and (4) hazardous vehicle maneuvers. Pahl (1972), Pahl, (1972), Case, Mosher, and Weber (1970), and Covault and Kirk (1964) studied the effects of off-ramp design on freeway traffic operations. The primary characteristics evaluated using

aerial photography were: (1) lane-change characteristics of freeway vehicles (both through and exiting vehicles), (2) gap acceptance characteristics of exiting vehicles, and (3) potential collisions. Pignataro, McShane, Crowley, Lee, and Roess (1972) analyzed weaving operations at 40 interchange locations across the country using aerial photography. The analysis of the photographic data was compared to the results obtained from the application of the 1965 Capacity Manual procedures. Vehicle volumes, speeds, and placement were the characteristics evaluated from the photographs. Remote sensing techniques could certainly be employed to evaluate the needed characteristics for each type of ramp design study.

References

- Jouzy and Michael, "Use and Design of Acceleration and Deceleration Lanes in Indiana"
- Taylor and Carter, "Photogrammetric Data Acquisition for a Freeway Ramp Operations Study"
- Hurst, Perchonok, and Seguin, "Vehicle Kinematics and Gap Acceptance"
- Wattleworth, Buhr, Drew, and Gerig, "Operational Effects of Some Entrance Ramp Geometrics on Freeway Merging"
- McDermott and McLean, "Improving Traffic Flow at Transfer Roadways on Collector-Distributor Type Roadways"
- Fukutome and Moskowitz, "Traffic Behavior and On-Ramp Design"
- Davidson, "Vehicular Paths in Certain Types of Intersection Areas"
- Pahl, "Gap Acceptance Characteristics in Freeway Traffic Flow"
- Pahl, "Lane Change Frequencies in Freeway Traffic Flow"

Case, Mosher, and Weber, "Exit Ramp Effects on Freeway System Operation and Control"

Covault and Kirk, "Influence of Off-Ramp Spacing on Traffic Flow Characteristics on Atlanta Freeway and Arterial Street System"

Pignataro, McShane, Crowley, Lee, and Roess, "Weaving Area Operations Study: Analysis and Recommendations"

AT GRADE INTERSECTION DESIGN STUDIES

Time-lapse photography was the most used technique to gather data on vehicles operating through at-grade intersections. The major problems associated with using this method of analysis were: (1) film capacity of cameras, (2) resolution and coverage, (3) expense, (4) establishing a reference system, and (5) data reduction. The utilization of remote sensing techniques would remove all of the disadvantages associated with time-lapse photography with the possible exception of the reference system. Methods for overcoming this disadvantage are discussed by Bleyl (1972).

Diwald and Nemeth (1972), Diwald (1972), Cribbins and Wylie (1971), Cribbins (1971), Ring and Carstens (1971), Nemeth and Treiterer (1969), and Dart (1968) all utilized time-lapse photography to analyze at-grade intersection designs. All of the investigators were confronted with the problem of coverage and camera film capacity. No adequate solutions to the problems were realized but camera-mirror arrangements were designed to increase the coverage of a single camera. A problem was then encountered because the movements photographed through the mirror were backwards. McShane and Rittvo (1970)

used time-lapse photography to generate data for the validation of a stochastic model of intersection traffic flows. Queue lengths and turning movements were the traffic characteristics evaluated. Neel (1971) used aerial photography to inventory the physical characteristics of 381 intersections in a New Orleans TOPICS (Traffic Operations Programs to Improve Capacity and Safety) study. No attempts were made to gather any traffic data from the photographs even though the data reduction would have presented few problems. There is no doubt that remote sensing and computer data reduction would greatly facilitate the analysis of at-grade intersections because of the numerous problems of using comparative systems such as time-lapse or aerial photography.

References

- Dieward and Nemeth, "Investigation of a Combined Photographic and Computer-Simulation Technique for Use in the Study of Isolated Intersections"
- Dieward, "A New Time-Lapse Data Collection Technique for Intersection Studies"
- Cribbins and Wylie, "Time-Lapse Photography: A Promising Tool for the Practicing Traffic Engineer"
- Cribbins, "Evaluation of Traffic Control Improvements by Time-Lapse Photography"
- Ring and Carstens, "Guidelines for the Inclusion of Left-Turn Lanes at Rural Highway Intersections"
- Nemeth and Treiterer, "A New Intersection Study Technique"
- Dart, "Left Turn Characteristics at Signalized Intersections on Four-Lane Arterial Streets"

McShane and Rittvo. "Statistics of Urban Queues and Turns at Signalized Intersections".

Neel. "Intersection Studies Using Low Altitude Aerial Photography"

HIGHWAY PLANNING STUDIES

Numerous types of highway and traffic planning studies were presented in the literature. Several study examples that utilized some form of aerial photographic techniques were: (1) traffic planning studies, (2) highway location and right-of-way studies, and (3) highway construction methodology studies.

Carstens (1972), Babcock (1971), and Hoge and Lykes (1970) presented research that utilized aerial photography to obtain traffic data which were used for future traffic planning in their respective areas. Typical traffic characteristics photographed were: (1) volumes, (2) speeds, (3) headways and delays, (4) land use changes, and (5) street pavement conditions. Mayhugh and Buechler (1971), Yount (1971), and Hamilton and Locate (1970) presented uses of aerial photography in the analysis of a proper highway location. Steinwinder and White (in progress) are developing techniques through which earth-work volumes can be estimated using aerial photographic techniques. Rib (1968) discussed the specific applications of remote sensing to general highway engineering studies. The recent advances in technology were described and examples of their use in the highway engineering field were listed.

References

Carstens, "A Study of Factors in Traffic Planning"

Babcock, "Land Use Changes and Traffic Generation on Controlled Access Highways in North Carolina"

Hoge and Lykes, "Inventory Your Streets For Better Management"

Mayhugh and Buechler, "Development of Photogrammetric Methods in Right-of-Way Operations"

Yount, "Location of a South Carolina Highway 11--Blue Ridge Parkway Connecting Highway"

Hamilton and Locate, "Using Air Photo Interpretation and a Socio-Ecological Reconnaissance in the Highway Route Selection Process"

Steinwinder and White, "Earthwork Measured by Field and Air-Photo Methods"

Rib, "Remote Sensing Applications to Highway Engineering"

PARKING AND PEDESTRIAN STUDIES

Parking and pedestrian studies using photographic techniques were not readily found in the literature. The application of remote sensing techniques to these studies is quite possible, however, and should be considered.

Schulman (1968) and Brant and Kinstlinger (1968) discussed the possibility of generating parking data from O-D studies conducted as a segment of the urban transportation planning process. Both studies presented positive relationships between O-D trips and parking demand. When origin-destination studies can be conducted by aerial photographic techniques, parking analyses could then be conducted with the data already obtained easily and profitably. SCATS (1968), Syrakis and Platt (1969), and Ruhm (1971) described parking studies that were conducted

using aerial photographic techniques. Each study provided very accurate results when compared to conventional ground survey results. Remote sensing could be applied to parking studies easily to inventory parking space usage and parking turnover. Pignataro, Fruin, McShane, and Crowley (1970) described a pedestrian design study conducted to determine design characteristics of the various pedestrian facilities. This type of study would possibly represent a future use of remote sensing due to the much smaller resolution that would be required to distinguish a single pedestrian.

References

- Schulman, "Parking as an Element Within the Comprehensive Transportation Planning Process"
- Brant and Kinstlinger, "Use of Origin-Destination Survey Data for Parking Analyses"
- SCATS, "Parking Study Using Aerial Photography for the Cities of Canton, Massillon, and North Canton, Ohio"
- Syrakis and Platt, "Aerial Photographic Parking Study Techniques"
- Ruhm, "Traffic Data Collection and Analysis by Photogrammetric Method"
- Pignataro, Fruin, McShane, and Crowley, "The Pedestrian, Level of Service Standards"

Annotated Bibliography

Athol, Patrick. INTERDEPENDENCE OF CERTAIN OPERATIONAL CHARACTERISTICS WITHIN A MOVING TRAFFIC STREAM. Highway Research Record 72, Highway Research Board, Washington, D. C., pp. 58-87, 1965.

Aerial photography was used to determine lane occupancy and density of traffic on the Congress Street Expressway in Chicago. Comparison of the aerial densities and lane occupancies with ground counts showed that the aerial data were very reliable. Travel times were also derived from the aerial data. Further analysis of the photographs provided vehicle volumes, speeds, headways, variations in speeds and headways, and differences in speed between certain vehicles. These parameters were related to freeway congestion and recommendations were made concerning traffic control measures to control congestion.

Authie, B., A. Riraud, and M. Leglise. ECONOMY WITH ACCURACY IN ASSEMBLING TRAFFIC DISPLACEMENT DATA BY AERIAL PHOTOGRAPHY. Australian Road Research, Vol. 4, No. 9, June, 1972, pp. 3-11.

The authors describe a technique that can be used to develop inexpensive but reliable traffic displacement data by aerial photography. The technique obviates the use of a stabilized chamber. A computer program was developed to offset the incidence of tilt in the photograph and another computer program was developed to set up a vehicle identification file. Tests showed that the maximum error for determining vehicle coordinates using the technique was approximately one meter per photograph measuring 400 square meters.

Babcock, W. F. LAND USE CHANGES AND TRAFFIC GERERATION ON CONTROLLED ACCESS HIGHWAYS IN NORTH CAROLINA. Project Number 70-4C, North Carolina State University, Raleigh, North Carolina, May, 1971.

This research was designed to provide a model which would predict land use changes along rural and urban controlled-access highways and the amount of traffic that would be generated by each type of land use change. All existing North Carolina controlled-access highways were analyzed using aerial photography and the model was developed from the basic land use and traffic data provided from the photographs.

Baggot, T. A. TRAFFIC DATA ACQUISITION FROM AERIAL PHOTOGRAPHS BY PHOTOGRAPHIC IMAGE PROCESSING. Highway Research Record 109, Highway Research Board, Washington, D. C., pp. 1-7, 1966.

This paper reports of the first attempts to use digital computers to analyze aerial photographs for recording specific characteristics of the traffic being photographed. The three primary charactexistics measured were traffic volume, density, and average speed. The operation of the computer while scanning the 16 shades of grey is described and the results of scanning photographs taken from 7,200 feet are presented. Limitations of the system were also presented, i. e., the inability to scan in shadows, or under trees and bridges.

Bates, J. M. DEVELOPMENT AND USE OF A STATEWIDE ORIGIN AND DESTINATION DATA BANK. Division of Highway Planning, Georgia State Highway Department, Atlanta, Georgia July, 1970.

This report describes the development of a procedure to extract external-external trip data from various study-oriented data files and to recode the data to county centroids. The trips were then assigned to a corridor-type assignment network for a statewide analysis. The author also described how data sources could be added, replaced, or deleted as new data becomes available or existing data becomes obsolete.

Bleyl, Robert L. TRAFFIC ANALYSIS OF TIME-LAPSE PHOTOGRAPHS WITHOUT EMPLOYING A PERSPECTIVE GRID. Traffic Engineering, Vol. 42, No. 11, August, 1972, pp. 29-31.

One of the most serious disadvantages of using time-lapse photography for traffic engineering studies has been the necessity to establish a grid reference system onto which the photographs are projected. In order that vehicles be tracked through the system accurately, the grid system was considered imperative. The author proposed that each vehicle can be accurately located by its coordinates and, through the use of a computer program, each vehicle can be traced through the system. A complete explanation of the subroutine and included terms was given at the end of the paper.

Bourne, K. M. ILLINOIS TOLLWAY IS EASY STREET WITH TOTAL COMMUNICATIONS SYSTEM. Communication News, Vol. 10, No. 1, January, 1973, pp. 24-29.

This paper describes the total communications system which provides the Illinois State Toll Highway Authority with coverage of 250 miles of tollway. The system consists of an extensive microwave network, a private telephone system, two-way base, mobile, and portable radios, pocket pagers, telemetering equipment, teleprinters, microfiche terminals, and test equipment, all keyed in to state police and Tollway police, and emergency and maintenance vehicles. Airplanes and a jet helicopter provide aerial coverage for traffic surveillance, parts relay, manhunts, and other emergencies.

Brant, Austin E., Jr., and Jack Kinstlinger. USE OF ORIGIN-DESTINATION SURVEY DATA FOR PARKING ANALYSIS. Highway Research Record 237, Highway Research Board, Washington, D. C., pp. 13-20, 1968.

This paper describes procedures by which parking demand can be determined from the origin-destination data normally collected as part of the travel pattern survey phase of a comprehensive transportation planning study. The procedures were applied to five urban areas in Massachusetts and the accuracy of the parking demand computed through the use of the procedures was evaluated by comparisons with both supply and usage. In all five cases, the procedures proved to provide accurate parking analysis and the results were used to improve existing parking facilities and also to recommend where additional parking facilities should be provided to handle the anticipated demand.

Caggiano, F. and L. Forte. DEVELOPMENT OF AN AERIAL RECONNAISSANCE SYSTEM FOR TRANSPORTATION OPERATIONS ANALYSIS. New York Port Authority, New York, New York (research in progress).

This research was responsible for the development and operation of Project Sky Count. Sky Count is a continuous research program whose objective is the development and application of airborne data acquisition systems for improved transportation operations analysis. By combining the principles of military photographic reconnaissance with sequential photo control and specialized data reduction techniques, pictorial images are recorded and then translated into useful numerical information for analysis of transportation operations. Examples of the transportation studies conducted using Sky Count data were: (1) Street network analysis, (2) Regional transportation analysis, (3) Route O-D studies, (4) "Before and after" improvement studies, and (5) Parking studies.

Capelle, Donald G. and Charles Pinnell. CAPACITY STUDY OF SIGNALIZED DIAMOND INTERCHANGES. Highway Research Bulletin 291, Highway Research Board, Washington, D. C., pp 1-25, 1961.

This study was designed to obtain traffic performance data which could be used to evaluate the capacity of signalized diamond interchanges. Two diamond interchanges along the Gulf Freeway in Houston, Texas, were analyzed using time-lapse photography during the peak periods of flow. Vehicle starting delays and headways at the interchanges were measured and the data were used to develop a basic approach to the determination of lane capacity. The results of the study provide insight into

the operational characteristics of vehicles at signalized diamond interchanges. Design procedures and charts for determining the capacity of diamond interchanges were developed and are presented in the report.

Carstens, R. L. A STUDY OF FACTORS IN TRAFFIC PLANNING.
Project Number 818, Engineering Research Institute, Iowa State University, Ames, Iowa, June, 1972.

The purpose of the research was to develop innovative techniques for planning transportation improvements. The research was concentrated in two important areas: (1) improved techniques for forecasting and synthesizing travel data, and (2) improvements in traffic signal control. Input data were obtained by time-lapse photography in order to evaluate modifications to existing methods of designing signal timing so as to minimize vehicle delays and operating costs.

Case, H. W., W. W. Mosher, and A. L. Weber. EXIT RAMP EFFECTS ON FREEWAY SYSTEM OPERATION AND CONTROL. Project Number CPR 11-4309, Institute of Transportation and Traffic Engineering, Berkeley, California, 1970.

The purpose of the project was to better understand the weaving and merging patterns that exiting motorists follow upstream of freeway exit ramps. A better understanding of these movements will contribute to improved criteria for geometric design, interchange spacing, signs and markings, and other traffic control devices. The objectives of the research were threefold: (1) to formulate a mathematical model which would describe motorists travel paths while approaching exit ramps, (2) to validate the mathematical model in a series of controlled

field measurements, and (3) to relate the results of the project to a variety of design and operational decisions. The mathematical model was developed and validated from data obtained from aerial and ground photography of the test ramp sites and also questionnaires mailed to motorists who used the ramps. Vehicle trajectories were taken from the photographs and verified by the returned questionnaires.

Committee on Science and Astronautics. REMOTE SENSING OF EARTH RESOURCES. U. S. Congress, Washington, D. C., 1972.

The papers presented to the panel on science and technology appraise the state-of-the-art on remote sensing. While an operational earth resources observation and management system is probably one or more decades away, experimental systems will be developed in the interim. The aerospace elements that require definition, research, and development are sensors, sensor platforms, and data acquisition and communications networks. The typical spatial resolution capabilities considered reasonable for typical sensor platform combinations are shown for selected data requirements for community environmental surveys, which include transportation network analysis.

Covault, Donald O. and Robert C. Kirk. INFLUENCE OF OFF-RAMP SPACING ON TRAFFIC FLOW CHARACTERISTICS ON ATLANTA FREEWAY AND ARTERIAL STREET SYSTEM. Highway Research Record 59, Highway Research Board, Washington, D. C., pp. 39-52, 1964.

The purpose of this study was to determine the influence of off-ramp spacing on the operational characteristics of the Atlanta Freeway System and the major city arterials influenced

by the freeway. Three off-ramps were closed for two weeks each during the a.m. peak hours. During the closures and during normal operations, time-lapse photography was used to collect data at four other locations along the freeway. From the photographs, speed and delay data were obtained along with vehicle volumes, densities, and overall travel times. The results showed that closing anyone of the off-ramps during the a.m. peak hours provided little or no improvement in traffic operations. A further conclusion was that off-ramps to the CBD should be spaced as close together as possible and design be consistent with the ability of the arterial streets to carry the traffic.

Creighton, Hamburg Incorporated. DATA REQUIREMENTS FOR METROPOLITAN TRANSPORTATION PLANNING. NCHRP Report 120, Highway Research Board, Washington, D. C., 1971.

The authors briefly discuss the potential of using aerial photographic techniques to provide data for the urban transportation planning process. Even though the authors feel that the present uses of aerial photography are limited (parking surveys and volume counting), they maintain that future technology will provide methods of greatly expanding the usefulness of aerial photography as related to urban transportation planning.

Cribbins, P. D. EVALUATION OF TRAFFIC CONTROL IMPROVEMENTS BY TIME-LAPSE PHOTOGRAPHY. North Carolina State University, Project Number 70-5, November, 1971.

This research project was designed to evaluate the use of time-lapse photography for measuring the effectiveness of traffic control improvements at selected intersections. The limitations of using time-lapse photography, i.e. resolution, coverage, and expense, are pointed out, and methods to overcome these shortcomings are considered. Results of the research are discussed in further detail in the paper by Cribbins and Wylie.

Cribbins, Paul D. and Philip L. Wylie. TIME-LAPSE PHOTOGRAPHY: A PROMISING TOOL FOR THE PRACTICING TRAFFIC ENGINEER. Traffic Engineering, Vol. 42, No. 3, December, 1971 pp. 40-45.

This paper describes a study which utilized time-lapse photography to evaluate the effectiveness of specific traffic control improvements in increasing capacity and flow while reducing accidents. Two intersections in Raleigh, North Carolina, were evaluated on a "before and after" basis. Improvements to the intersections included the addition of travel lanes, addition of presence detectors in certain critical lanes, pavement markings, signal timing, and changes in alignment. Color film was used to facilitate the identification of individual vehicles and separate indications of the traffic signals. The time-lapse photography proved to be very helpful in the analysis and critical information such as queue lengths, vehicle delays, lane volumes and distributions, vehicle classifications, and vehicle headways were obtained fairly easily.

Dart, Olin K., Jr. LEFT TURN CHARACTERISTICS AT SIGNALIZED INTERSECTIONS ON FOUR-LANE ARTERIAL STREETS. Highway Research Record 230, Highway Research Board, Washington, D. C., pp. 45-59, 1968.

This paper describes a research project which was designed to determine the left-turn characteristics that would be suitable for defining a left-turn component of a signalized intersection computer simulation model. Time-lapse photography was used to collect data at six intersections in four Texas cities. The primary characteristic of the traffic studied was the left-turn gap acceptance distribution and its variation with the type of left-turn (non-stop or stopped). Over 1000 left-turning vehicles were observed and the several of the more significant conclusions reached were: (1) 16-mm time-lapse photography with one second intervals was satisfactory, (2) gap acceptance distributions for non-stop and stopped left-turning vehicles were significantly different, and (3) the gap acceptance characteristics of traffic turning left from channelized sections were not significantly different from turns made from unchannelized sections.

Davidson, Bruce M. VEHICULAR PATHS IN CERTAIN TYPES OF INTERSECTION AREAS. Proceedings of the Highway Research Board, Vol. 36, January 7-11, 1957, pp. 576-586.

The study attempted to analyze the various design features of Wisconsin interchanges with respect to motorists' reaction. Time-lapse photography was used to trace the path of the vehicles through the interchange. Eleven interchanges were photographed and analysis of the data led to the following conclusions: (1) weaving lanes needed to be longer to allow

a smooth merge rather than a hazardous darting merge,
(2) drivers should not be confronted with more than one decision at a time, and (3) intersection design should not provide turning movements that conflict with driver common sense or intuition.

DeSalvo, J. S., editor. CONFERENCE ON REGIONAL TRANSPORTATION PLANNING, PROCEEDINGS: THE RAND CORPORATION. Project R-706-DOT, The Rand Corporation, Santa Monica, California, May, 1971.

The report describes a conference, conceived and sponsored by DOT, and planned and coordinated by the Rand Corporation, that explored the idea that some form of transportation planning entity should be created between national and local planning agencies. The primary objective of the conference was to consider the economic and administrative advantages and disadvantages of conducting transportation studies on a regional basis. The first nine chapters of the report describe the nine papers presented at the conference. The papers dealt with the technology that has already been developed or will be required to accomplish the goals of regional planning. The tenth chapter summarizes the recommendations of the nine papers and lists the final recommendations of the conference.

Dieward, Walter J. A NEW TIME-LAPSE DATA COLLECTION TECHNIQUE FOR INTERSECTION STUDIES. Traffic Engineering, Vol. 42, No. 10, July, 1972, pp. 46-48, 57.

This paper describes a novel camera arrangement that allows two cameras to photograph up to four approaches of an intersection. Standard techniques allowed for one camera to

photograph two opposite approaches only, however, resolution became a serious problem with this method. Another method was developed to photograph up to four approaches with a single camera but the middle of the intersection was left out. Also, photographs taken through any mirror arrangements resulted in the movements being backwards. A final problem was that the cameras would not hold enough film for more than 30 minutes of continuous surveillance. The system consisted of two camera and mirror units. Each unit was installed to allow two approaches at a right angle to each other to be photographed. This arrangement allowed the clearest resolution and complete coverage of all pedestrian-vehicle movements.

Dieward, Walter and Zoltan A. Nemeth. INVESTIGATION OF A COMBINED PHOTOGRAPHIC AND COMPUTER SIMULATION TECHNIQUE FOR USE IN THE STUDY OF ISOLATED INTERSECTIONS. Highway Research Record 398, Highway Research Board, Washington, D. C., pp. 12-14, 1972.

This study represented an attempt to use time-lapse photography to provide input information for a computer simulation of an isolated signalized intersection. The authors also attempted to overcome several of the short comings of time-lapse photography experienced by previous investigators. The only success reported by the authors was the increased capacity of the cameras that would allow 30 minutes of data to be filmed at a rate of one frame per second. A computer simulation model was developed using the GPSS-360 simulation language and was validated with the photographic data.

Dueker, K. J. and F. E. Horton. INFORMATION SYSTEMS FOR THE URBAN TRANSPORTATION PLANNING PROCESS. Project Number Urt-32, Iowa University, Iowa City, Iowa, June, 1971.

The authors discuss the development of an information system required in the continuing urban transportation planning process. The differences in data requirements for urban transportation planners and the city management are discussed as a justification for developing separate information systems. The common data needs of each group are listed so that duplication of effort can be avoided. The authors concluded that technology will present few problems for the data collection process but that the major problems will be in management where organization and coordination of the systems become difficult.

Everall, P. F. URBAN FREEWAY SURVEILLANCE AND CONTROL: THE STATE OF THE ART. Traffic Systems Division, Federal Highway Administration, U. S. Department of Transportation, Washington, D. C., November, 1972.

This state-of-the-art report offers advice on the selection and design of various freeway surveillance and control systems and discusses eight solution types. The development and use of necessary hardware were described. The various control systems can be operated with different strategies, and the effects of these forms of operation were discussed. Until technology can be developed to facilitate aerial control, the author felt that inductive loop detectors provide the best type of vehicle sensor with magnetometers and sonic detectors as feasible alternatives.

Fukutome, Ichiro, and Karl Moskowitz. TRAFFIC BEHAVIOR AND ON-RAMP DESIGN. Highway Research Bulletin 235, Highway Research Board, Washington, D. C., pp. 38-72, 1959.

The purpose of the research was to evaluate three separate types of entrance ramp terminal design. Three types of entrance ramp terminal designs were painted successively at an on-ramp location on a San Francisco freeway. Time-lapse photography and ground surveys were used to evaluate the traffic behavior for each terminal design configuration. Vehicle paths and entering speed were the major parameters used to judge the effectiveness of each terminal design. The results showed that a terminal design with a parallel lane of adequate length, a small angle of convergence, and a uniform overall shape was the most desirable type.

Goodwin, Browne C. and Robert L. Lawrence. INVESTIGATION OF LANE DROPS. Highway Research Record 388, Highway Research Board, Washington, D. C., pp. 45-61, 1972.

The objective of the research project was to evaluate the effect of various lane-drop configurations on safety and traffic operations on several freeways. Aerial photography was used to record traffic volumes at three lane-drop sites in the Los Angeles area. Reduction of the photographs provided time-history trajectories of all vehicles, measures of traffic operations (densities and speeds), and measures of safety (potential collisions). There were no significant differences in safety among the three configurations but speeds were much lower at the site where the two heavier travelled lanes were merged together than at the other sites where merging was

performed on the right. The authors recommended that aerial photography be used to study all types of freeway operations because of the safety considerations. The primary limitation of aerial photography currently is the cost, but further development will make aerial photography a viable tool for the traffic engineer.

Greenshields, Bruce D. THE PHOTOGRAPHIC METHOD OF STUDYING TRAFFIC BEHAVIOR. Proceedings of the Highway Research Board, Vol. 13, Washington, D. C., December 7-8, 1933, pp. 328-399.

This paper reports the initial use of time-lapse photography for obtaining accurate data on traffic behavior. The overall camera setup and reference marker system were described in detail. A sample test was taken on a two-lane highway with 6,000 vehicles being filmed. A relationship for vehicle headways was derived from the data. The author also suggested that the filming technique be used to analyze (1) vehicle passing behavior, (2) traffic congestion, (3) driver behavior at traffic signals, and (4) traffic volumes and speeds.

Haley, Charles E., Edward M. Hall, and Arnold A. Johnson. TRAVEL TIME--A MEASURE OF SERVICE AND A CRITERION FOR IMPROVEMENT PRIORITIES. Highway Research Record 35, Highway Research Board, Washington, D. C., pp. 1-17, 1963.

This research represents an effort to develop a street improvement priority formula for urban areas. Studies were conducted in Phoenix, Arizona, and San Diego, California, to test the relationship between travel time and level of service for urban streets and freeways. Travel time surveys were

conducted by conventional means and time contour maps were drafted to illustrate the relative levels of service provided by various routes. Although the travel studies were conducted in the field, the research is valuable because of the relationship derived between travel time and level of service. Aerial photographic techniques and computer data reduction would facilitate the data collection process and enable small to medium sized cities to develop the criteria described in this work.

Hamilton, L. S. and D. S. Locate. USING AIR PHOTO INTERPRETATION AND A SOCIO-ECOLOGICAL RECONNAISSANCE IN THE HIGHWAY ROUTE SELECTION PROCESS. Agricultural Experiment Station, Cornell University, Ithaca, New York, 1970.

A method was developed to select highway routes which would do the least damage to the variety of existing ecological systems, land uses, and educational, scientific, and cultural values that can be identified within a region. Aerial photographic interpretation was a useful tool in the process of resource analysis, and attempts were made to find where the techniques failed to identify values in a region that should be projected. The objective within the stated guidelines was to decide where a proposed highway, based on reasonable and feasible engineering criteria, should not be located. Using map overlays and field examinations, proposed corridors were then suggested. The proposed relocation of a major state highway was used as a test case.

Herd, Lloyd O. AN AERIAL PHOTOGRAPHIC TECHNIQUE FOR PRESENTING DISPLACEMENT DATA. Highway Research Record 232, Highway Research Board, Washington, D. C., pp. 64-67, 1968.

This paper discusses the use of open-shutter photography from a hovering aircraft to record the path of a lighted moving object (vehicle) against a background of low illumination (highway). A digital computer was used to reduce the data from the photographs and plot the coordinates of the vehicles. Critical data concerning the traffic flow were: (1) vehicle headways, (2) densities and volumes, (3) paths of vehicle movements, (4) vehicle speed and acceleration, and (5) the effect of grades or alignment on vehicle performance. The author suggested that further applications should be directed at parking studies and, by targeting individual vehicles, O-D studies or vehicle identification systems.

Hodgkins, Edmund A. EFFECT OF BUSES ON FREEWAY CAPACITY. Highway Research Record 59, Highway Research Board, Washington, D. C., pp. 66-82, 1964.

The purpose of this research was twofold: (1) to evaluate the effects of buses on mixed freeway traffic, and (2) to determine the maximum capacity of an exclusive bus lane. Time-lapse photography was used to study seven separate locations in major urban areas across the country. The basic method of analysis was the "cluster" analysis. The theory behind the cluster analysis is that capacity flows are being approached on any actual highway when the driver of a vehicle begins to feel restricted by the vehicles around him. Clusters of vehicles (vehicle with headways of seven seconds or less) were

broken out and average speeds calculated for each. The cluster value was correlated to the capacity of the freeway. In this way, the passenger vehicle equivalency factor of a single bus and the maximum capacity of an exclusive bus lane could be determined. Results showed that an equivalency factor of 1.6 was reasonable for level terrain and that the maximum capacity of an exclusive bus lane was 1,300 buses per hour per lane (as compared to 2,000 passenger vehicles per hour per lane).

Hoge, Carson H. and J. E. Lykes, Jr. INVENTORY YOUR STREETS FOR BETTER MANAGEMENT. American City, Vol. 85, No. 3, March, 1970, pp. 98-99.

This article describes a method of systems management for city street maintenance and development based on a detailed inventory designed for electronic data processing. Aerial photography was used to provide the basic street inventory data and was supplemented with ground field data. Priority ratings were provided based on observable conditions in conformance with detailed written criteria. Improvements would be made on the basis of the priorities of needed projects. The inventory system is designed to serve as a tool in the development and budgeting of the annual street maintenance program. To justify aerial photographic techniques, the city would have to be fairly large (>100,000) and have suitable electronic equipment for data reduction and storage.

Horton, Frank and Duane F. Marble. REGIONAL INFORMATION SYSTEMS: REMOTE SENSING INPUTS. Presented at the 35th Annual Meeting of the American Society of Photogrammetry, Washington, D. C., March 9-14, 1969.

The authors describe the development of a regional information system using remote sensing techniques. Such a system is considered vital in the long- and short-term decision-making policies of social, economic, and political planners. The authors emphasized that many of the urban problems now being faced by society were caused by the lack of appropriate data for decision makers in the past. Information systems should be developed and evaluated by the following properties: (1) capacity, (2) quality, (3) compatibility, (4) timeliness, (5) coherence, (6) flexibility, (7) dependability, and (8) economy. Recent developments, research, and experiments in the field of remote sensing indicate that this technology will provide the capability to gather and store tremendous amounts of valuable information that can be used to solve many urban problems.

Humphreys, Jack B. EFFECT OF TRUCKS ON THE URBAN FREEWAY. Highway Research Record 308, Highway Research Board, Washington, D. C., pp. 62-79, 1970.

This paper reports of an investigation to study the effect of trucks or grades or both on urban freeway level of service. The parameter used to measure this effect was acceleration noise, a measure of the changes in velocity a driver makes over a section of roadway. A section of the Gulf Freeway in Houston, Texas, was studied using aerial time-lapse photography. The model was developed and validated using the aerial data. The results of the study showed that acceleration noise was not a

suitable measure of the effect of trucks on the freeway level of service.

Hurst, Paul M., Kenneth Perchonok, and Edmund L. Seguin.
VEHICLE KINEMATICS AND GAP ACCEPTANCE. Journal of Applied Psychology, Vol. 52, No. 4, August, 1968, pp. 321-324.

The authors analyzed traffic data taken from aerial photographs to isolate the variables which determined gap acceptability in a merging situation. From this data, 28 alternative expressions were computed, involving positional and velocity information for the lead, following, and subject vehicles. Each of the indices were regarded as a correlate of gap acceptability and correlation ratios were computed between acceptance-rejection behavior and the value of each index at the "decision point". Values of the index, η , ranged from 0.187 to 0.733 and all but the lowest value were significant at the one percent level of significance. The highest correlations were obtained with expressions involving time or speed relationships between subject and following vehicles. Investigations were also presented in the use of the η values in the assessment of comparative degrees of "confusion" as a function of roadway and/or traffic-control parameters.

Hutchinson, B. G. ESTABLISHING URBAN TRANSPORTATION DEMANDS BY SYNTHETIC PROCEDURES. Engineering Journal, Vol. 54, No. 6, June, 1971, pp. 22-26.

This paper presents a technique which can be used to predict traffic patterns and flows cheaper and simpler than standard trip generation techniques. The author contended that a knowledge of the spatial pattern of the peak-hour work

trips was adequate for transportation network planning. The data requirements that would allow the gravity model to be calibrated synthetically were provided. Relationships were provided from which the trip length frequency distribution may be developed from the population of the city. Equations which describe work-trip productions and attractions were also presented. The author concluded that the adoption of the recommended procedures realized savings of about 50 percent in a typical transportation planning study.

Johnson, A. N. MARYLAND AERIAL SURVEY OF HIGHWAY TRAFFIC BETWEEN BALTIMORE AND WASHINGTON. Proceedings of the Highway Research Board, Vol. 8, Washington, D. C., December, 13-14, 1928, pp. 106-115.

The first reported aerial survey of traffic was conducted by the State Roads Commission of Maryland in 1927. Six targeted vehicles were placed in the traffic stream and ground traffic volume counts were conducted at four locations along the route to validate the results. The route was 29 miles long. Photographs were taken every 13 seconds for the flight that took 27 minutes resulting in 127 photographs. Relationships were derived for roadway volume rates based on average vehicle speeds and headways. The ground volume counts verified the aerial surveys satisfactorily.

Jordan, Thomas D. DEVELOPMENT OF THE SKY COUNT TECHNIQUE FOR HIGHWAY TRAFFIC ANALYSIS. Highway Research Record 19, Highway Research Board, Washington, D. C., pp. 35-46, 1963 .

This paper describes some of the applications of operation Sky Count that were used to gather important traffic engineering data. An analysis of the Lincoln Tunnel traffic situation was described where the photographs were taken from an altitude of 10,000 feet. Vehicle speeds, densities, and volumes were obtained from the photographs. A second study was initiated to analyze the traffic leaving the New York International Airport. Photographs were taken from 8,000 feet and the usual data were extracted. In addition, peak hour volumes were plotted to determine critical periods of congestion. The author suggested other applications of the aerial surveys, some of which were: (1) studies of vehicle platooning, (2) estimation of traffic volumes by sampling critical streets, and (3) urban transportation O-D surveys for large sections of the city.

Jouzy, Neddy C. and Harold L. Michael. USE AND DESIGN OF ACCELERATION AND DECELERATION LANES IN INDIANA. Highway Research Record 9, Highway Research Board, Washington, D. C., pp. 25-51, 1963.

The speed and lateral placement of vehicles on the various types of acceleration and deceleration lanes along the Indiana Toll Road and Indiana Interstate System were studied in an attempt to correlate the speed-change lane design with traffic behavior and driver requirements. Another primary consideration involved the speed-change lane designs that provided the most efficient and safest operation. Time-lapse photography and a

radar speed meter were used to gather the necessary data at 15 acceleration lane locations and 13 deceleration lane sites. The conclusions reached were as follows: (1) many drivers do not know how to use speed change lanes, (2) speed-change lane traffic had little effect on through traffic speeds, (3) through lanes should be on a tangent section, (4) tapered acceleration lanes provided the best traffic operations, (5) parallel acceleration lanes allowed drivers to merge too soon and at too low a speed, (6) location along a curve section affected speed-change lane usage, (7) drivers did not obey advisory or warning signs placed near the beginning of the deceleration lane, (8) most of the traffic began decelerating in the through lanes, and (9) the taper design provided the best traffic operations.

Keese, Charles J., Charles Pinnell, and William R. McCasland.
A STUDY OF FREEWAY TRAFFIC OPERATIONS. Highway Research
Bulletin 235, Highway Research Board, Washington, D. C.,
pp. 73-132, 1959.

This study was conducted on freeways in Houston, Dallas, and Fort Worth. Time-lapse photography was used to monitor traffic operations on the freeway study sites. Particular emphasis was placed on traffic operations and capacity, freeway volume control, lane use and vehicle placement, entrance ramp controls, weaving, and freeway median design. The results of the study showed that particular care should be taken in the design and operation of on- and off-ramps and interchanges. The usual statistics of volume, speed, and density were also obtained in addition to the previously mentioned data.

Kiefer, Ralph W. and James W. Scherz. CIVIL ENGINEERING APPLICATIONS OF AIRBORNE REMOTE SENSING TECHNOLOGY. Presented at the National Meeting on Transportation Engineering, American Society of Civil Engineers, Washington, D. C., July 21-25, 1969.

The authors discussed recent developments in remote sensing technology that have produced instruments capable of sensing far beyond the visual and photographic range of the electromagnetic spectrum and into the thermal infrared and radar and microwave regions. Systems such as side-looking airborne radar that map terrain day or night, almost without regard for weather conditions, were discussed. New uses for existing systems and highly sophisticated systems currently under development were discussed. The use of photography thermal imagery, multispectral imagery, and side-looking airborne radar were emphasized. As a conclusion to the paper, the remote sensing instruments that have a demonstrated or potential use in civil engineering applications were listed and described by the authors.

Leser, Frank G., III. PHOTOGRAPHIC O-D TRAFFIC SURVEY. Traffic Engineering, Vol. 40, No. 6, March, 1970, pp. 49-50.

This paper describes how photographic techniques can be combined with standard post card and questionnaire surveys to conduct O-D studies. The photographic equipment was used to provide a complete record of all vehicles that crossed a cordon line. The cameras were installed so that each rear license tag would be photographed. A sample was chosen from the film and names and addresses were established from motor vehicle registration files. Questionnaires were sent to this sample

and 50 percent were completed and returned. The typical cost per sample was approximately \$0.23 while standard O-D surveys cost \$0.50-\$1.00 and create drivers irritation through excessive delays.

McCasland, William T. COMPARISON OF TWO TECHNIQUES OF AERIAL PHOTOGRAPHY FOR APPLICATION IN FREEWAY TRAFFIC OPERATIONS STUDIES. Highway Research Record 65, Highway Research Board, Washington, D. C., pp. 95-115, 1963.

The primary purpose of this study was to compare continuous-strip stereoscopic photography with time-lapse photography with respect to traffic operations studies. Traffic movements on the Gulf Freeway in Houston, Texas, were photographed using both methods of aerial photography. Time-lapse photography proved to be more suitable for traffic density studies, acceleration studies, lane distribution studies, and vehicle classification studies. Continuous strip photography proved to be more suitable for measuring time dependent traffic parameters (speed, volume) and generally provided more coverage than time-lapse photography.

McDermott, Joseph M. and Charles H. McLean. IMPROVING TRAFFIC FLOW AT TRANSFER ROADWAYS ON COLLECTOR-DISTRIBUTOR TYPE EXPRESSWAYS. Highway Research Record 59, Highway Research Board, Washington, D. C., pp. 83-103, 1963.

This study was designed to evaluate the effect of pavement marking improvements installed on a section of the Dan Ryan Expressway in Chicago. Time-lapse photography was used to provide a complete record of the traffic behavior at the test sites "before and after" the improvements were installed. Of particular interest were the number of hazardous maneuvers made, and

the vehicle speeds through the test sections. Speeds and volumes were not affected by the new pavement markings but the number of lane changes were significantly reduced. Also a considerable reduction of hazardous movements was realized.

McShane, W. R. and S. M. Rittvo. STATISTICS OF URBAN QUEUES AND TURNS AT SIGNALIZED INTERSECTIONS. Project Number TR-0668-03, Polytechnic Institute of Brooklyn, Brooklyn, New York, September, 1970.

This project represents an attempt to define the parameters of a stochastic model of intersection queues and turning movements. Time-lapse photography was used to gather the information for the study. The project has not been completed as yet and is currently listed as being inactive.

Malo, A. F., H. S. Mika, and V. P. Walbridge. TRAFFIC BEHAVIOR ON AN URBAN EXPRESSWAY. Highway Research Bulletin 235, Highway Research Board, Washington, D. C., pp. 19-37, 1959.

This research represents one of the earliest applications of time-lapse photography to analyze urban freeway congestion. The John C. Lodge Expressway and Edsel B. Ford Expressway in Detroit were filmed for eight days with approximately 64,000 vehicles being recorded during that time. The vehicle data were reduced from the photographs by manual methods and transferred to computer cards. Some of the information obtained were: (1) traffic composition, (2) lane distributions, (3) speed profiles, (4) volume counts, (5) vehicle headways, (6) freeway densities, and (7) accident records.

May, Adolf D., Jr., G. Ahlborn, and W. Gillfillan. FREEWAY OPERATIONS STUDY (DISTRICT 04). Project Number RTA-13280, Institute of Transportation and Traffic Engineering, Berkeley, California, (research in progress).

This research is a comprehensive freeway operations study of 140 miles of the most critical freeways in the San Francisco area. The primary objective of the project was to provide a better understanding of driver behavior as influenced by the traffic and geometric conditions of the freeway. Aerial photography was used to gather the data for the project: density contour maps, travel time maps, and traffic flow maps. The data were used to determine the critical sections and to estimate the effect of each section on overall traffic operations. Improved means of data collection and reduction were also developed. The second phase of the project consisted of the selection of critical sections, analysis of each critical section, and recommendations for improvements of each section.

Mayhugh, J. and M. Buechler. DEVELOPMENT OF PHOTOGRAMMETRIC METHODS IN RIGHT-OF-WAY OPERATIONS. Project Number 15-69, Aerial Engineering and Right-of-way Division, Ohio, Department of Highways, July, 1971.

This study represents an attempt to provide a more orderly and accelerated approach to the right-of-way plan phase of the right-of-way operation. Evaluations of the application of photogrammetric techniques were made by standard practices in recording title documents for the preparation of right-of-way maps, descriptions, and court exhibits.

Missouri State Highway Commission. FREEWAY SURVEILLANCE STUDIES. Project Number HRP-1(8)-61, Jefferson City, Missouri (research in progress).

This research represents a continuation of several previous projects concerning freeway operations in St. Louis and Kansas City. Aerial photography was used to determine current levels of service on the freeways and critical areas were analyzed in detail to determine the need for traffic control measures.

Mittelbach, F. G. and M. I. Schneider. REMOTE SENSING: WITH SPECIAL REFERENCE TO URBAN AND REGIONAL TRANSPORTATION MANAGEMENT. Project Number Urt-j, School of Architecture and Urban Planning, University of California at Los Angeles, August, 1971.

This research effort represents an attempt to utilize remote sensing techniques to monitor a distinct phenomenon (moving vehicle) based upon its distinct energy discharge. The report described remote sensing devices with reference to the different frequency ranges in which they operate. The equipment may be of two types: (1) active sensors which illuminate the target area by transmitting radiation of a particular wavelength and sampling its reflection by the target, or (2) passive sensors which only sample the radiation emitted by specific sources. A major problem in most contemporary applications of remote sensing occurred at the data collection-data reduction interface. While most urban uses of the concept rely upon some form of aerial photography, analysis of the data has generally required visual interpretation by nonautomated means. Attempts to digitize such information have incurred prohibitive cost-

effectiveness ratios to date, however, the report also cited several potential applications in the area of transportation planning and management. Particular applications of interest are the abilities of the remote sensor to plot traffic flows and define land use interfaces within an urban system. Promising applications listed are inventorying such observable data as transportation facilities, travel behavior, traffic movement, and land use. Remote sensing could also be used to assist in transportation decision-making, to generate random data for planning an information base, or as an educational device.

Moore, Eric G. and Barry S. Wellar. URBAN DATA COLLECTION BY AIRBORNE SENSOR. Journal of the American Institute of Planners, Vol. 35, No. 1, January, 1969, pp. 35-43.

This paper discusses recent technological advances which make remote sensors a viable solution to many data-collection problems encountered by urban planners and researchers. The major types of sensors were discussed and a framework for the integration of remote sensors with an urban data system was described. Remote sensors were shown to possess particular advantages of timeliness and flexibility when compared to other data collection systems. Future research and development will be needed to evaluate the performance of the remote sensor with respect to compatibility and reliability.

Munjal, P. K., Y. S. Hsu, and R. L. Lawrence. ANALYSIS AND VALIDATION OF LANE-DROP EFFECTS ON MULTI-LANE FREEWAYS. Transportation Research, Vol. 5, No. 4, December, 1971, pp. 257-266.

The purpose of this research was to develop a mathematical model that would describe the density perturbation on a multi-lane freeway. Aerial photographic field data were taken on two selected freeway lane-drop sites to validate the model. The hydrodynamic theory of traffic flow was the basis of the model development. Several types of lane drops were analyzed during the development of the model. In each case the wave propagation of density perturbations was obtained with the knowledge of the boundary conditions.

Neel, Hibbett. INTERSECTION STUDIES USING LOW ALTITUDE AERIAL PHOTOGRAPHY. Traffic Engineering, Vol. 41, No. 10, July, 1971, pp. 16-17, 63.

This paper briefly describes the aerial photographic technique utilized for the study of 381 intersections in New Orleans. The photographs were taken from an altitude of 1,000 feet and were used purely for inventory purposes for the TOPICS analysis of the intersections. Traffic control devices, light poles, buildings, vegetation and other physical features of each intersection were located easily. Condition diagrams were then scaled from the photographs. No attempt was made to evaluate any vehicle characteristics from the study. The aerial methods cost approximately the same as ground crews and were about one-third to one-half the costs of conventional aerial photography. Approximately 100 intersections were flown per day.

Nemeth, Zoltan A. and Joseph Treiterer. A NEW INTERSECTION STUDY TECHNIQUE. Highway Research Record 286, Highway Research Board, Washington, D. C., pp. 62-73, 1969.

This research was designed to explore new techniques of measuring the operational characteristics of urban intersections and also to evaluate whether traffic control devices were being best utilized at the intersections. A camera-mirror arrangement was designed to continuously survey all four approaches of the intersection and installed over the center of the intersection of Ohio State Highways 3 and 161. A computer simulation model of the intersection was developed from the photographic data and various traffic control measures were evaluated. Signal phasing and type of signal control (fixed time, semi-actuated, and fully-actuated) were varied and evaluated. Limitations of the camera arrangement were as follows: (1) only nine minutes could be filmed at a time, (2) the center of intersection was obstructed from the camera, and (3) the operation proved to be very expensive.

Osborn, John A. CHARTING NEW TRANSPORTATION ENVIRONMENT. American Society of Civil Engineering, Journal of the Surveying and Mapping Division, Vol. 96, No. SU2, September, 1970, pp. 265-286.

The author discussed the current demands for transportation planning that require a considerable increase in conventional mapping and surveying capabilities. Advances in transportation modes and the demands these advances will place on society were discussed. The author concluded the paper by discussing methods through which the latest technology could be applied to these problems. Computer applications such as automatic mapping and

information banks and remote sensing technology such as side-looking radar and infrared photography were discussed. The possibility of using remote sensing technology in urban transportation studies was also considered.

Pahl, Juergen. GAP ACCEPTANCE CHARACTERISTICS IN FREEWAY TRAFFIC FLOW. Highway Research Record 409, Highway Research Board, Washington, D. C., pp. 57-63, 1972.

Aerial photographic data were used to determine average spatial and time sizes of the accepted gaps and the lag gaps in gap-acceptance maneuvers for exiting vehicles close to their intended off-ramp and for through vehicles as a function of the distance upstream from the off-ramp. In addition, attempts were made to quantify the accident risk imposed by each lane change on the lag car of the accepted gap. Various flow volumes were studied on an eight-, six-, and a four-lane freeway location. The results showed that the average spatial and time gap and lag gap sizes of gaps accepted by exiting vehicles decreased as the exiting vehicles approached the off-ramp. The corresponding average gaps for through vehicles showed little dependency on the distance from the off-ramp. Average gap and lag gap sizes of gaps accepted by exiting and through vehicles decreased with increased flow volumes. A larger accident risk was accepted by exiting vehicles than by through vehicles in their lane changes, whereas the accident risk imposed on the lag car of the accepted gap was smaller for lane changes by exiting vehicles than by through vehicles.

Pahl, Juergen. LANE CHANGE FREQUENCIES IN FREEWAY TRAFFIC FLOW. Highway Research Record 409, Highway Research Board, Washington, D. C., pp. 17-25, 1972.

This paper presents an empirical study of the lane-change frequencies of exiting vehicles close to their intended off-ramp and of through vehicles for an eight-, six-, and four-lane freeway. The results were related to various flow volumes and distances upstream from the off-ramp. Aerial photographic techniques were used to record the data and digital computers were used to obtain time-space relationships of all the vehicles in each study area. The results showed that the greatest frequency of exiting-vehicle lane changes was toward the right lane and that a corresponding increased frequency of through-vehicle lane changes was toward the left lane. At the off-ramp, as the exiting vehicles left the freeway, through vehicles were shown to move back toward the right lane and to have high lane-change frequencies.

PARKING STUDY USING AERIAL PHOTOGRAPHY FOR THE CITIES OF CANTON, MASSILLON, AND NORTH CANTON, OHIO. Stark County Area Transportation Study, Canton, Ohio, 1968.

This report compared a method of collecting parking usage and duration characteristics using color aerial photography and the standard field method of collecting the parking information. The two methods were evaluated as to cost, time, manpower requirements, output, and accuracy of the results. Most conventional data collection procedures involve extensive field studies which prove to be both costly and time consuming. SCATS eliminated the conventional parking usage field study

through the use of 15-minute aerial photography. The procedure produced extremely accurate data and resulted in an 85 percent savings in time and a 72 percent savings in cost.

Pellog, M., L. Stoch, and U. Etrog. AERIAL PHOTOGRAPHS FOR TRAFFIC STUDIES IN URBAN AREAS. Technion-Israel Institute Technology, October, 1969.

Initial investigations of this research were involved with establishing suitable scales of photography for investigating various traffic characteristics. To accomplish this task, aerial photographs were taken at different flying heights from a helicopter. Following this, a test flight was made to obtain photographs at a multi-purpose scale and traffic characteristics were determined with the purpose of selecting suitable laboratory procedures, recommending proper equipment, and determining the efficiency of studying the traffic stream in general and also single vehicles.

Pignataro, Louis J., William R. McShane, Kenneth W. Crowley, Bumjung Lee, and Roger P. Roess. WEAVING AREA OPERATIONS STUDY: ANALYSIS AND RECOMMENDATIONS. Highway Research Record 398, Highway Research Board, Washington, D. C., pp. 15-30, 1972.

The purposes of this research study were threefold:

(1) analyze and evaluate the weaving section procedures of the 1965 Capacity Manual, (2) develop a study program that leads to improved techniques for the design and analysis of weaving sections, and (3) implement the study program to achieve the improved techniques. Field data were obtained from aerial photographs of approximately 40 locations throughout the United States. The data were reduced and punched onto computer cards.

Computer programs were written to analyze the data and compute such traffic measures as the volumes of the various movements, space and time mean speeds, and travel times. The sites were analyzed using the 1965 Capacity Manual procedures and compared to the field data. For basic weaves and ramp weaves, the Capacity Manual procedure produced both poorer and better levels of service than those actually experienced in the field. For major weaves, the Capacity Manual weaving procedure tended to predict poorer levels of service than actually occurred. For ramp weave cases, the Capacity Manual weaving procedures produced more accurate estimates of levels of service than either of the ramp capacity procedures, both of which tended to predict better levels of service than those actually experienced in the field.

Pignataro, Louis J., J. J. Fruin, William R. McShane, and Kenneth W. Crowley. THE PEDESTRIAN, LEVEL OF SERVICE STANDARDS. Project Number TR-0968-01, Polytechnic Institute of Brooklyn, Brooklyn, New York, June, 1970.

The research was designed to establish levels of service for pedestrians through the determination of proper standards for design of doors, corridors, stairs, ramps, escalators, sidewalks, and queueing activities under various levels of demand and for different types of facilities such as air, bus, marine, and rail passenger terminals. The input data were gathered at existing terminal by aerial time-lapse photography.

Rib, Harold T. REMOTE SENSING APPLICATIONS TO HIGHWAY ENGINEERING. Public Roads, Vol. 35, No. 2, June 1968, pp. 29-36.

In recent years, the availability of new remote sensors-- radar, infrared, multi-channel--has initiated a new era in the application of interpretation techniques in highway engineering. The data provided by the many types of sensors furnish information previously unobtainable, or available only at great expense. The areas of possible applications of remote sensors in the highway field were described. Several examples were included to demonstrate the value of remote sensors in various aspects of highway engineering. Also discussed was a summary of a Public Roads research program in remote sensing.

Rice, Joseph F. ADOPTION OF AERIAL SURVEY METHODS FOR TRAFFIC OPERATIONS. Highway Research Record 19, Highway Research Board, Washington, D. C., pp. 47-52, 1963.

This paper describes a project which utilized helicopters to take aerial photographs of problem sections of freeway during the a.m. and p.m. rush hours in the Washington, D. C. area. Traffic engineers and law enforcement officials were also invited to fly in the helicopter while the photographs were being taken to observe the traffic conditions from their respective points of view. The results of the study concluded that not only do the photographs provide plentiful data for analysis of most freeway congestion situations, but the presence of traffic engineers and law enforcement officials lent additional help to the solution of the problem sections. Potential uses of the photography included detour routing and improvement of traffic operations and freeway design.

Richter, Dennis M. URBAN PHOTO INDEX FOR EASTERN U. S.
Photogrammetric Engineering, Vol. 37, No. 1, January, 1971,
pp. 54-66.

The author discusses the great potential for using sequential aerial photography for urban planning and industrial site location analyses. Past usage of small-scale aerial photography and also the advances in technology which now allows small-scale photography to be used were discussed in detail. Eight photographs were provided to illustrate specific areas of the eastern United States. Information was provided concerning the photograph scales which were obtained and the possible applications for the photographs as related to urban planning and development.

Ring, S. L. and R. L. Carstens. GUIDELINES FOR THE INCLUSION OF LEFT-TURN LANES AT RURAL HIGHWAY INTERSECTIONS.
Highway Research Record 371, Highway Research Board,
Washington, D. C., pp. 64-79, 1971.

This research was intended to provide a reasonable design guide for rural at-grade intersections. Basic input data obtained using time-lapse photography were vehicle headways and delays, left turn gap acceptance characteristics, and vehicle speeds and volume. The observed vehicle headways were not fitted to any theoretical distribution but the vehicle delays were input into an economic analysis of the provision of a left turn lane. Input to the economic analysis included construction costs, road-user costs, and annual maintenance costs. Warrants for various volume and speed conditions were derived and provided in the appendix of the report.

Ruhm, K. TRAFFIC DATA COLLECTION AND ANALYSIS BY PHOTOGRAMMETRIC METHOD. Traffic engineering and Control, Vol. 13, No. 8, December, 1971, pp. 337-341.

This study utilized repeated strip aerial photography to obtain traffic data which were analyzed by traditional manual methods. A photogrammetric parking study was conducted of an 80-space parking lot. From the same photographs, speed studies were taken from the surrounding street system which covered an area of approximately one half square kilometer. The five kilometers of street all had a 50 kilometer per hour speed limit. The speed sample contained 161 speed records and yielded an average speed of 30 kilometers per hour. The simplicity of operation and economy compared with traditional ground surveys strongly supported the implementation of photogrammetry for traffic and land use-transportation studies.

Schaefer, W. E. and John West. A NEW LOOK IN FREEWAY OPERATION. Traffic Engineering, Vol. 39, No. 11, August, 1969, pp. 30-31, 34-35.

This paper reports on the Los Angeles Area Freeway Surveillance and Control Project organized in 1965. Within the project, three programs have been initiated to reduce the freeway traffic problems in the LA area: (1) up-grading the existing freeway system, (2) developing a freeway surveillance and control system, and (3) developing, testing, and applying new operational techniques for specific freeway traffic problems. A helicopter and light airplane were used to take aerial photographs of traffic congestion and density-contour maps were developed and analyzed. Improvements were recommended,

implemented, and then evaluated using the same aerial techniques. The helicopter was also part of the communications system which was used to warn motorists of hazards or bottlenecks, notify officials of emergency situations, remove accident victims, or notify maintenance crews of debris that should be removed from the freeway.

Schulman, Lawrence J. PARKING AS AN ELEMENT WITHIN THE COMPREHENSIVE TRANSPORTATION PLANNING PROCESS. Public Roads, Vol. 34, No. 12, April, 1968, pp. 18-26.

The current status of parking analysis and its relation to the comprehensive transportation planning process are evaluated. Included was a discussion of the basic relationships behind a driver's choice of parking location and a proposal for a new procedure for improving parking analysis and its coordination within the planning process. The recommended procedure included the use of O-D survey data for measuring parking demand. (see Brant and Kinstlinger for results)

Steinwinder, J. P. and J. H. White. EARTHWORK MEASUREMENT BY FIELD AND AIR-PHOTO METHODS. Project Number 46, Mississippi State Highway Department (research in progress)

Procedures necessary for determining earthwork pay quantities using airphoto methods were established. By study and comparison with conventional field methods, determinations were made of the degree of error inherent in the two methods used for determining earth work quantities. Work cost comparisons were also made.

Sweet, Clyde E., Jr. GUIDELINES FOR THE ADMINISTRATION OF URBAN TRANSPORTATION PLANNING. Institute of Traffic Engineers, April, 1969.

This report is one of three studies published in the Informational Reports on Transportation Planning series. The organization of studies, comments on implementing transportation plans, and observations on coordinating the continuing planning process within a comprehensive planning framework were provided. The final section covered the continuing cooperative planning process and its relationship to day-to-day urban traffic and planning operations. Anticipated costs of conventional ground surveys were discussed and the possible applications of aerial photographic techniques were also briefly discussed.

Syrakis, Thomas A. and John R. Platt. AERIAL PHOTOGRAPHIC PARKING STUDY TECHNIQUES. Highway Research Record 267, Highway Research Board, Washington, D. C., pp. 15-28, 1969.

Color aerial photography was used in place of conventional ground observations for collecting data on parking use and duration in Stark County, Ohio. A flight pattern was designed to photograph the cities of Canton, Massillon, and North Canton every 15 minutes between 10 a.m. and 6 p.m. on an average weekday. The resulting color photography provided the necessary information to evaluate the on-and off-street parking conditions for the central traffic district of each city. During each flight, ground data were simultaneously being collected in an eight-block area of downtown Canton. Using the control data, comparisons were developed between the two

techniques to check the accuracy of the aerial collection process. Close correlations were found and the aerial procedures resulted in tremendous savings of time and cost. The data have since been utilized in other traffic and transportation studies of the area.

Taylor, James I. and Robert G. Carter. PHOTOGRAMMETRIC DATA ACQUISITION FOR A FREEWAY RAMP OPERATIONS STUDY. Highway Research Record 319, Highway Research Board, Washington, D. C., pp. 78-87, 1970.

This paper describes the photographic techniques used to measure traffic kinematics of interest in an investigation of the effects of environmental conditions (weather and illumination) on the decision of a ramp driver to accept or reject a mainstream gap. An on-ramp along the Long Island Expressway was chosen as the test site. Time-lapse photography was used to monitor the driver's behavior on the ramp. The photo coordinates of each of the vehicles were measured at the Pictorial Data Transducer and converted to ground coordinates. The ground coordinates were then used to measure such vehicle characteristics as length, headway, and speed. A total of 3,400 vehicle trajectories were computed and filed in a data bank for the gap acceptance/rejection analysis. The overall average error derived from the operation, including the reduction, transformation, and calculation methods, was approximately 2.5 feet per vehicle.

Tolle, J. E. THE LOGNORMAL HEADWAY DISTRIBUTION MODEL.
Traffic Engineering and Control, Vol. 13, No. 1, May, 1971,
pp. 22-24.

The author used aerial photographic techniques to collect the data required to test the lognormal mathematical model as a vehicular headway distribution. The lognormal probability distribution assumes that the logarithms of the sample headways have a normal distribution. Methods to estimate the necessary parameters of the model were developed and described. The model was tested for a wide range of traffic volumes and the Kolomogrov-Smirnov and Chi-square "goodness-of-fit" tests were used to evaluate the model.

Treiterer, Joseph. INVESTIGATION OF TRAFFIC DYNAMICS BY AERIAL PHOTOGRAMMETRY TECHNIQUES. Project Number EES-278, Engineering Experiment Station, Ohio State University, Columbus, Ohio (research in progress)

This study represents an attempt to use aerial photogrammetric techniques to investigate traffic dynamics. Input from the photographs was used to test the limits of validity of various traffic flow models. Further applications of aerial photography are being tested, particularly with the refinement of high quality aerial equipment and data processing techniques. Also being examined are improved techniques for transferring data from film to tape to cards for data processing equipment.

Treiterer, Joseph. LONGITUDINAL TRAFFIC CONTROL BY INFRARED SENSING. Highway Research Record 421, Highway Research Board, Washington, D. C., pp. 78-84, 1972.

The author presents a study of two types of infrared remote-sensing systems for longitudinal traffic control that can be used to prevent rear-end collisions and breakdowns in traffic flow. A prototype of the infrared source-sensor was built and tested in freeway driving. The limitations of the system were that all vehicles had to be instrumented for the system to be effective and only vehicles in the same lane could be controlled. The author also proposed that the present driver information system provided by traffic signs be improved by infrared sensing for spacing of vehicles and by lane coding for continuous driver information. The author recommended that the control system cost be borne by the vehicle owner in the interest of safety and emphasized that capacity could be increased about 4,000 vehicles per hour per lane for 40 mile per hour freeway traffic.

Treiterer, Joseph and James I. Taylor. TRAFFIC FLOW INVESTIGATIONS BY PHOTOGRAMMETRIC TECHNIQUES. Highway Research Record 142, Highway Research Board, Washington, D. C., pp. 1-12, 1966.

This paper presents a technique which was developed to measure traffic movement in order to test and validate traffic flow models. The primary objective was to develop a method for determining vehicle headways and speeds for a platoon of vehicles at short intervals of time. The procedure consisted of placing a test vehicle in the traffic stream and following that vehicle with a helicopter which would take aerial photographs of the

traffic stream at fixed intervals of time. A freeway in Columbus, Ohio, was analyzed using the proposed technique and very accurate vehicle trajectories were obtained from the investigation. The authors noted that a very serious limitation of the method was the data reduction of the photographs.

Wagner, F. A. and Adolf D. May, Jr. USE OF AERIAL PHOTOGRAPHY IN FREEWAY TRAFFIC OPERATIONS STUDIES. Highway Research Record 19, Highway Research Board, Washington, D. C., pp. 24-34, 1963.

This paper presents a project designed to test the feasibility of using aerial time-lapse photography to gather data for the analysis of freeway traffic conditions in Los Angeles. The critical traffic parameter measured was traffic density. The study utilized a light airplane and a helicopter and concluded that the helicopter was best suited for individual sections of freeway and the airplane could be used for longer sections of freeway where photographs would only be needed every five to ten minutes. The authors described the procedure required to reduce the data from the photographs and derived density contour maps from the data. Also described was the analysis of the density contour maps in order to locate potential sources of congestion.

Wattleworth, Joseph A., Claude Archambault, and Charles E. Wallace. DEVELOPMENT OF TECHNIQUES FOR ANALYSIS OF OPERATION OF MAJOR INTERCHANGES. Highway Research Record 257, Highway Research Board, Washington, D. C., p. 80, 1968.

This research represents an effort to evaluate the traffic operations on freeway-to-freeway interchanges using aerial photographic techniques and also input-output techniques.

Because of the heavy volumes of traffic often present at such interchanges, analysis by conventional methods was practically impossible. The paper presented the preliminary attempts of developing such an analysis technique, described the problems encountered in the analysis of major interchanges, and identified the measures of effectiveness (MOE) of major interchanges. The two analysis techniques were described and tested on two Detroit freeway interchanges.

Wattleworth, Joseph A., Johann H. Buhr, Donald R. Drew, and Frank A. Gerig, Jr. OPERATIONAL EFFECTS OF SOME ENTRANCE RAMP GEOMETRICS ON FREEWAY MERGING. Highway Research Record 208, Highway Research Board, Washington, D. C., pp. 79-122, 1967.

The objective of the project was to study the effects of the following specific geometric variables on entrance ramp operation: (1) acceleration lane length, (2) angle of convergence, and (3) ramp grade. Studies were made of 29 entrance ramps in major urban areas across the country. Acceleration lanes ranged from 240 to 1,500 feet and the angles of convergence ranged from 1 to 14 degrees. Aerial time-lapse photography was utilized to obtain the following data: (1) time-space plots of the vehicles, (2) entrance speeds, (3) merging speeds, (4) relative speeds, and (5) acceleration lane use. The results showed that: (1) acceleration lanes should not be narrow, (2) operations on ramps with angles of convergence less than three degrees were excellent, and (3) angle of convergence had more effect on operations than acceleration lane length but both design features were important to efficient traffic operations.

Wildermuth, B. EFFECT OF LANE PLACEMENT OF TRUCK TRAFFIC ON FREEWAY FLOW CHARACTERISTICS. Wilbur Smith and Associates, Columbia, South Carolina, May, 1971.

The purpose of this research was to develop a digital simulation model for freeway traffic flow. The model was used to test the effect of restricting truck traffic to a specified lane or lanes during the peak hours. The model was calibrated from data gathered by three hours of time-lapse photography taken on an Atlanta freeway. The model was adapted from similar model developed by Midwest Research Institute.

Wobber, Frank J. ORBITAL PHOTOS APPLIED TO THE ENVIRONMENT. Photogrammetric Engineering, Vol. 36, No. 8, August, 1970, pp. 852-864.

Photography taken from test rockets and Gemini and Apollo manned spacecraft was analyzed to demonstrate the advantages and limitations of using small-scale or low-resolution images for studying environmental problems. As cities evolve into megalopolises, it is necessary to recognize the wider scope of environmental data needs and to apply techniques with an inherent capability for regional analysis. Orbital photography can be used in environmental studies (air quality, water quality, and socio-economic problems) and transportation studies (land use patterns and transportation network identification). For assessing relationships between transportation lines and urban growth, orbital images, at a minimum, provide timely base maps from which urban planning decisions can be made.

Yount, David E. LOCATION OF A SOUTH CAROLINA HIGHWAY 11 - BLUE RIDGE PARKWAY CONNECTING HIGHWAY. Unpublished Master's thesis, Civil Engineering Department, Clemson University, Clemson, South Carolina, December, 1971.

This report described the procedure used in locating a scenic highway in the undeveloped mountainous area of Pickens County, South Carolina, and Transylvania County, North Carolina, through the use of aerial photographic interpretation techniques. Selection of the route alignment was based on three factors: (1) minimization of construction costs, (2) maximization of the economic and recreational development of the area surrounding the route, and (3) minimization of the disturbance to the existing environment. The study concluded that aerial photography could be used with a high degree of success in highway location studies. The photographs provided an optimum means of evaluating the effects of such critical factors as topography, drainage conditions, soil conditions, and land use on the route location.